(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
14 June 2001 (14.06.2001)

PCT

(10) International Publication Number
WO 01/42809 A2

(51) International Patent Classification[7]: G01S

(21) International Application Number: PCT/US00/33152

(22) International Filing Date: 6 December 2000 (06.12.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/169,285 7 December 1999 (07.12.1999) US
60/180,689 7 February 2000 (07.02.2000) US

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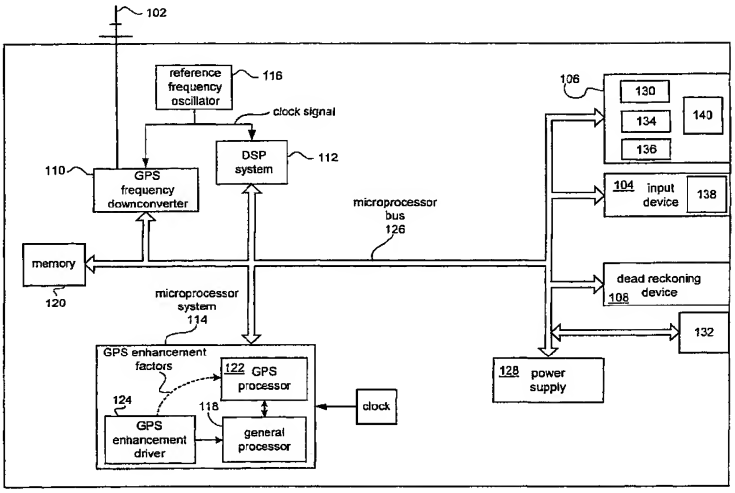
(81) Designated State *(national)*: JP.

(84) Designated States *(regional)*: European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR).

Published:
— *Without international search report and to be republished upon receipt of that report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: GPS ATHLETIC PERFORMANCE MONITOR METHODS AND APPARATUS THEREOF



(57) Abstract: A system for automatic monitoring real-time athletic performance of a user is described. A portable unit (100) having a GPS receiver capable of providing GPS velocity data to a processor unit (122) includes a processor unit (122) coupled to a database(120) having information such as physical characteristics, weight, age, and gender, is able to provide a updated readout to a display unit (106) of the user's ongoing athletic performance statistics. Such statistics include elevation gain, current speed, current heading, current elevation, calories burned, anticipated calories burned (based upon a pre-selected course), and others. By using Doppler shift based GPS velocity measurements, the athletic performance monitor is able to provide an accurate accounting of a user's athletic performance in real time. In some cases, a virtual competition can be held whereby users at different locations and/or at different times can conduct a virtual competition using the athletic performance monitor coupled to a server computer.

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GPS ATHLETIC PERFORMANCE MONITOR METHODS AND APPARATUS THEREOF

BACKGROUND OF THE INVENTION

1. Field of Invention

The invention relates generally to performance monitoring. More particularly, methods and apparatus for monitoring an athlete's real time performance using a global positioning satellite system (GPS) are disclosed.

2. Description of Relevant Art

Outdoor endurance activities have become very popular not only because they are enjoyable and healthy, but also because they provide opportunities for competition, camaraderie, and a structured regimen. It would be highly beneficial for an individual participating in an outdoor endurance activity such as running, cross-country skiing, in-line skating, or outdoor swimming to be able to monitor his or her performance in metrics such as speed, distance, slope, elevation, and calories on a real-time basis. Additionally, as part of a particular training program, an athlete will want to be able to keep track of his or her performance for a particular event as well as be able to store for later comparison with subsequent athletic events. For example, if a runner desires to track his or her performance over a period of time, various physical characteristics of the runner, such as age, weight, and gender, for example, could be used to evaluate the runner's performance against both his or her individual performances, either as an average or against trend data over a designated period of time. In addition to being able to gauge their own particular athletic performances

against their own historical record, an athlete would also like to be able to compare his or her own performance against a reference performance typical of, for example, a person having similar physical characteristics. In this way, an athlete could gauge his or her own athletic prowess and abilities against an accepted reference and be able to determine, for example, what percentile he or she falls in relation to his or her particular cohort of runners.

In addition to being able to ascertain one's own performance against a hypothetical norm, an athlete would also like to be able to compete against other athletes. Such competitions historically have been held in meets, or other local physical competitions where athletes meet in person and compete. It would also be desirable to be able to compete against an opponent even in those situations where both opponents can not be physically in the same location, by the use of a network such as the Internet. However, being able to track each individual, until recently, has been impractical to say the least.

Further, structured real-time coaching is presently available to very few athletes, and the need to train on measured courses in order to undergo traditional highly structured workouts severely limits an athlete's options in pursuing advanced training regimens. This situation is worsened when the athlete wishes to train in an area in which he or she is unfamiliar with local training routes. A means to provide real-time performance coaching, pre-planned structured workouts, and access to a compilation of local training routes would be highly beneficial to athletes.

With the advent of the global positioning system (GPS), the ability to track a particular object, be it a car, boat, or person, on the surface of the Earth in real time has greatly improved. GPS technology enables the possibility of compact portable devices that monitor and store a user's location, speed, and elevation in real time.

However, there remain several impediments to the widespread adoption of GPS-based portable athletic monitors: (1) GPS signals are easily blocked when the athlete passes under heavy foliage or by high buildings; (2) GPS slope and elevation measurements are highly inaccurate, compromising a GPS performance monitor's ability to log the elevation profile and thus accurately assess athletic performance; and (3) GPS speed measurements based on analysis of time-stamped location waypoints are not accurate enough for performance analysis.

There have been several attempts in the past to incorporate a GPS device into a portable athletic monitor, but none has been particularly successful. One such attempt is represented by U.S. Patent 6,002,982. This invention uses GPS only to log user location as a function of time, in parallel with another sensor that monitors a performance metric such as speed. It does not utilize the GPS to measure performance and thereby is limited to activities such as bicycling in which speed measurement can be performed using other technology. It also does not provide for on-line racing, workout databases, or route databases, nor does it address the above-mentioned impediments to GPS use.

U.S. patent 6,013,007 utilizes a GPS receiver to record a series of time-stamped location waypoints, from which it deduces a user's athletic performance. This approach to GPS velocity measurement is significantly less accurate than GPS carrier-wave Doppler velocity measurement, leading in typical situations to objectionably high velocity error. Further, this patent also fails to address any of the above impediments to GPS use.

U.S. patent 6,032,108 details a GPS athletic performance monitor that minimizes the effects of errors due to navigational reference systems and the intentional slight dithering of civilian GPS. This dithering, referred to as Selective

Availability, has since been terminated by the U.S. government. Errors due to reference system are also not a concern as long as the same system is used consistently. Similarly to the other patents named above, this patent does not address any of the above impediments to GPS use.

Therefore, what is needed is a portable GPS based athletic performance monitor and system capable of providing consistently available, accurate, real time athletic performance specific to a particular user. In addition, the portable GPS monitor should be able to interface with a distributed network of computers, such as the Internet, in order to provide a link to a virtual community of athletes.

SUMMARY OF THE INVENTION

The invention relates to an apparatus and method for monitoring an athlete's real-time performance using the Global Positioning System (GPS). In one implementation, a portable athletic performance monitoring and training system arranged to provide athletic performance data associated with an athletic performance is described. The system includes a GPS receiver and a memory device storing selected data such as measured user performance metrics and a digital elevation model (DEM) database that describes the local elevation profile. The DEM data serve to improve the accuracy of the GPS elevation and speed measurements as well as to improve the tolerance of the system to satellite blockage.

The system also includes a processor arranged to calculate carrier-wave Doppler-shift based user velocity based upon data received from the GPS receiver and the DEM, and to calculate selected athletic performance feedback data using the calculated user velocity and other data such as the elevation profile and the user physical characteristics. The use of Doppler based velocity measurements gives accuracies in the range of 0.1 mph in typical GPS receivers, which is the highest accuracy typically required for useful assessment of athletic activities.

The system further includes a data I/O port arranged to provide a data interface between the system and an external computing device, whereby the data can be transmitted to and from a computer network such as the Internet. This enables a host of competitive, community, and experience-enhancing functions including virtual races, favorite-routes databases, regimen databases, performance benchmarking, and route mapping and planning. Further, the Internet connection enhances the performance of GPS by enabling the seamless downloading of DEM data for the area in which an athlete is training and by enabling the downloading of

precise satellite location ("ephemeris") data, which greatly speeds up the system's initial start-up time.

These and other advantages of the present invention will become apparent upon reading the following detailed descriptions and studying the various figures of the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with further advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 represents a particular implementation a GPS personal trainer 100 in accordance with an embodiment of the invention that is typically carried on or by a user during a particular training session.

Fig. 2 illustrates a block diagram of a GPS frequency down-converter in accordance with an embodiment of the invention.

Fig. 3 illustrates a block diagram of a DSP system in accordance with an embodiment of the invention.

Fig. 4 illustrates a flowchart describing a process for initializing the trainer in accordance with an embodiment of the invention.

Fig. 5 illustrates a flowchart detailing the process whereby the trainer is set to act in the passive mode in accordance with an embodiment of the invention.

Fig. 6 shows a flowchart detailing the active mode in accordance with an embodiment of the invention.

Fig. 7 is a flowchart describing a particular implementation of the mode selection operation as a training mode in accordance with an embodiment of the invention.

Fig. 8 shows a flowchart detailing one implementation of the course mode in accordance with an embodiment of the invention.

Fig. 9 is a flowchart detailing an implementation of the workout mode in accordance with an embodiment of the invention.

Fig. 10 shows a flowchart detailing an implementation of a cross country mode in accordance with an embodiment of the invention.

Fig. 11 illustrates a number of trainers coupled to form a virtual competition in accordance with an embodiment of the invention.

Fig. 12 illustrates a computer system that can be employed to implement the present invention.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The following description is provided to enable any person skilled in the art to make and use the invention and sets forth the best modes contemplated by the inventor for carrying out the invention. Various modifications, however, will remain readily apparent to those skilled in the art, since the basic principles of the present invention have been defined herein specifically to provide a novel GPS based personal trainer and methods of use thereof.

Reference will now be made in detail to a preferred embodiment of the invention. An example of the preferred embodiment is illustrated in the accompanying drawings. While the invention will be described in conjunction with a preferred embodiment, it will be understood that it is not intended to limit the invention to one preferred embodiment. To the contrary, it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the invention as defined by the appended claims.

Broadly speaking, the invention relates to an improved method, apparatus and system for automatic monitoring in real-time athletic performance of a user. In one implementation, the invention provides a portable unit having a GPS receiver capable of providing GPS velocity data to a processor unit. The processor unit, being coupled to a database having information such as physical characteristic data such as weight, age, and gender, stored therein, is able to provide a updated readout to a display unit of the user's ongoing athletic performance statistics. Such statistics include elevation gain, current speed, current heading, current elevation, calories burned, anticipated calories burned (based upon a preselected course), and others. By using Doppler shift based GPS velocity measurements, the inventive athletic performance monitor is able to provide an accurate accounting of a user's athletic performance.

In a preferred embodiment, the inventive monitor can be coupled to a distributed network of computers, such as the Internet, by way of an I/O port coupled to external circuitry, such as a personal computer, personal digital assistant (PDA), modem, etc. In this way, the user can download selected data related to, for example, other athlete's performance data, selected courses, training programs, etc. so as to be a part of a virtual community of athletes each of whom interact with each other in either a real time basis or in some cases, during what is referred to as a virtual competition, such as a race.

Fig. 1 represents a particular implementation a GPS personal trainer 100 in accordance with an embodiment of the invention that is typically carried on or by a user during a particular training session. The GPS personal trainer 100 is arranged to receive GPS satellite signals from one or more GPS satellites having a line of sight to a GPS antenna 102 and to determine a location of the GPS antenna 102 and a time of observation. The GPS personal trainer 100 also includes one or more input devices 104 to receive requests from a user, one or more output devices 106 to display information to a user as well as communicate with external circuitry by way of, for example, a data port (not shown but described below). It should be noted that the user input devices 104 have associated labels to enable a user to know how to request an operation of the GPS personal trainer 100. In one embodiment, the labels are hard or permanent. Alternatively, the labels are soft or can be changed by the user according to a menu of operations. In some embodiments, the GPS personal trainer 100 can optionally include one or more dead reckoning devices 108 to provide direction information or change of location information. Such dead reckoning devices include altimeters, accelerometers, cadence measurements sensors and the like.

In the described embodiment, the GPS antenna 102 receives the GPS satellite signals and provides a GPS antenna signal having a frequency of approximately 1.575 GHz. A GPS frequency down converter 110 receives and down converts the GPS antenna signal to a GPS intermediate frequency (IF) signal suitable for digital processing. A digital signal processor (DSP) system 112 receives the GPS IF signal from the GPS frequency down converter 110 and provides digital signals representing correlation information, for example, to a microprocessor system 114. It should be noted that in some embodiments the DSP system 112 can be physically integrated into the microprocessor system 114. A reference frequency oscillator 116 provides a system clock signal to the frequency down converter 110 and the DSP system 112. Optionally, the system clock signal is provided by an external source.

More particularly, Fig. 2 illustrates a block diagram of a GPS frequency down-converter 200 in accordance with an embodiment of the invention. It should be noted that the down-converter 200 in one possible implementation of the down-converter 110 and should therefore not be construed as limiting either the scope or intent of the invention. As configured, the GPS frequency down-converter 200 provides the GPS IF signal to the DSP system 112. The GPS frequency down-converter 200 uses radio frequency RF analog integrated circuit design techniques and fabrication processes well known to those skilled in the arts. A preamplifier 202 receives the GPS antenna signal at a frequency of approximately 1.575 GHz and issues an amplified signal to an RF to IF channel 204. In an alternative embodiment, a preamplifier in the GPS antenna 102 eliminates the requirement for the preamplifier 202. Typically, a preamplifier in the GPS antenna 102 and/or the preamplifier 202 is required in order to provide good signal to noise ratio for the GPS IF signal. A local oscillator system 206 receives the system clock signal at one frequency from the

reference frequency oscillator 116 (or external clock source) and provides one or more local oscillator signals at one or more other frequencies to the RF to IF channel 204. The RF to IF channel 204 uses the local oscillator signals to down-convert the frequency of the amplified GPS antenna signal to the GPS IF signal and passes the IF signal to an optional first sampler 208. The first sampler 208 synchronizes the GPS IF signal to the clock signal, quantizes the amplitude of the GPS IF signal and issues a digital GPS IF signal to the DSP system 112.

Fig. 3 illustrates a block diagram of a DSP system 300 in accordance with an embodiment of the invention. It should be noted that the DSP system 300 is one possible implementation of the DSP 112 and should therefore not be construed as limiting either the scope or intent of the invention. The DSP system 300 has any number of operational modes, the most commonly used one is where the GPS IF signal is acquired and tracked. In the described embodiment, the DSP system 300 uses digital integrated circuit design techniques and fabrication processes well known to those skilled in the arts. A second sampler 302 synchronizes the GPS IF signal to the system clock signal and quantizes the amplitude of the GPS IF signal to provide a digital GPS IF signal to one or more DSP channels 304. The second sampler 302 can be included in each of the DSP channels 304, however since the input and the output of the second sampler 302 is common for all the DSP channels, a cost savings is achieved by using a single second sampler 302.

The microprocessor system 114 assigns each DSP channel 304 to process the GPS satellite signals as represented by the GPS IF signal from one or more individual GPS satellites. The DSP channel 304 is assigned only one GPS satellite signal in parallel operation and is assigned more than one GPS satellite signal in serial operation. More particularly, in serial operation, the DSP channel 304 time sequences

through the assigned GPS satellite signals. Each of the DSP channels 304 includes at least one carrier correlator 306 and at least one code correlator 308 to receive the GPS IF signal, to receive the system clock signal and to correlate the carrier and the code, respectively, in the GPS satellite signal as assigned by the microprocessor system 114.

The carrier correlator 306 correlates the carrier of the GPS satellite signal to a carrier Numerically Controlled Oscillator (NCO) included in the carrier correlator 306. The microprocessor system 114 receives and processes correlation information from the carrier correlator 306 and provides digital signals to adjust the carrier NCO frequency. The code correlator 308 correlates the C/A code PRN modulation to a code NCO included in the code correlator 308 and a PRN sequence that is specified by the microprocessor system 114 in order to assign a GPS satellite signal to the DSP channel 304. The times of start of the GPS satellite signals are processed to determine relative distances and speeds (pseudoranges and pseudorange rates) for the GPS satellites.

Referring back to Fig. 1, the microprocessor system 114 includes a general processor unit 118 capable of executing a pre-determined set of instructions stored in a memory 120 as pre-coded software instructions and data. The general processor unit 118 is coupled to both a GPS processor 122 and a GPS enhancement driver 124. The GPS processor 122 serves to convert the measurements from the DSP system 112 into actual location/velocity solutions for the user. The GPS enhancement driver 124 serves to integrate data from GPS enhancements such as a DEM database and the dead reckoning device 108 into the GPS and the performance calculations. It should be noted that commonly the GPS processor 122 and the GPS enhancement driver 124 may be physically integrated into the general processor unit 118. It should also be

noted that the general processor unit 118 is capable of receiving tracking data provided by the GPS processor 122 and provide any number and kind of positional data. Such positional data can be used in any number of training modes and includes, instantaneous speed, instantaneous bearing (i.e., compass direction), average speed, distance covered, various location coordinates, absolute elevation as well as rate of elevation change (or slope).

The microprocessor system 114 operates in a conventional manner to receive digital signals from the DSP system 112, to process the digital signals by executing pre-coded software stored in the memory 120 and to issue digital signals to control the various elements of the GPS personal trainer 100. In one implementation, the microprocessor system 114 receives digital signals representing, for example, correlation information from the DSP system 112 and issues digital signals representing location, rate of change of location, direction, and/or time to the output devices 106. A bus 126 carries digital signals between the microprocessor system 114 and the various elements of the GPS personal trainer 100. A power supply unit 128 can take the form of a rechargeable battery such as a NiCd, LiH, and the like. By using such long life batteries, the trainer 100 can used for extensive training sessions typical of long term athletic endeavors such as, but not limited to, marathon training, triathlon training, ultra-marathon training, orienteering, etc.

Accordingly, the processor 114 is capable of generating any number and kind of training data useful in providing the trainer 100 with the capability of operating in any number of user specific training modes. Such training modes include a pre-planned workout mode where the trainer 100, in real time, updates the user's current speed and based upon data stored in the memory 120, provides real time feedback whether to speed up or slow down. Other modes include a pre-planned route mode

where the trainer 100 uses a pre-selected route stored in the memory 120 to provide real time directions to the user in order to stay on course. In a preferred embodiment, the output devices 106 includes a display unit 130 that is used to provide the user with the aforementioned feedback data as well as providing the display of other information and data useful to the user. Such data includes a workout summary that can be used to review and critique a particular workout session. In addition, the data can include any appropriate information that the user deems appropriate.

In the described embodiment, the system includes an I/O data port 132 coupled to the memory 120 by way of the bus 126 that is capable of downloading or uploading data to or from external circuitry, such as a computer system, either local or remote.

In a preferred embodiment of the invention, a Digital Elevation Model (DEM) database is stored into the memory 120. The function of the DEM is to improve the system's performance in periods of partial satellite blockage and to improve the elevation and velocity accuracy of the system. In some cases, the data in the DEM can be provided by an external source such as the Internet by way of the I/O port 132 from a master database on a remote server. Furthermore, using the display 130 or the display on an external computing device, the data in the DEM can be used to create visual images of the terrain for use by the user of the trainer 100. Basically any application in which the trainer 100 is located at the level of the surface of the earth as mapped in DEM's, and where the trainer 100 moves in areas of unknown or changing elevation, can be appropriately enhanced.

In the described embodiment, the DEM gives the elevation, Z, as a function of the horizontal position X and Y. A preferred embodiment would include a DEM based upon the USGS's National Elevation Database (NED), which provides

seamless elevation data across the entire United States. It should be noted that there are similar DEM's available for the other parts of the world. DEM's are generally data files showing the elevation in meters on a grid throughout the mapped area, typically with points spaced every arc-second (about 30 meters). Such elevation data are accurate to typically about 5 meters. It should be noted that DEM's are commonly produced using other coordinate systems than that of GPS, and that therefore the DEM data should preferably be converted to the GPS coordinate system in order to maximize accuracy. Even though a typical 7.5-minute map in an uncompressed format would occupy about 400 kilobytes of memory on board the device, this amount of memory is small and inexpensive and a typical application would typically require only one or perhaps a small number of such maps to be loaded. Using well-understood data compression techniques, even less memory would be necessary, or conversely, more data could be stored if so desired.

The use of the DEM would enhance the GPS position functions as follows. For normal 3-dimensional GPS, the device must track four satellites, from which it can calculate the three position quantities X, Y, Z, plus time simultaneously. Using a DEM, the device needs only track three satellites, because it knows Z as a function of X and Y. The device would use its three satellites to solve for X, Y, Z(X,Y) and time simultaneously. Thus in challenging environments where fewer than four satellites are visible, the device can still maintain a high quality position fix. Moreover, the accuracy of the elevation readings Z is greatly enhanced.

Similarly, for velocity readings, the GPS receiver may either simply take differences in the position readings, in which case the above benefit in position accuracy translates into velocity accuracy; or it may calculate speed using the Doppler effect. In the latter case, the device uses the measured Doppler shifts of the signals

from several satellites to calculate the velocity components dX/dt, dY/dt, and dZ/dt. Using a DEM, the processor can impose the constraint given by the total derivative of Z(X,Y) onto the Doppler speed calculation: $dZ/dt = \partial Z/\partial X\ dX/dt + \partial Z/\partial Y\ dY/dt$. Doing so again reduces the number of satellites required by one and improves accuracy.

The overall accuracy of position and velocity determination is enhanced by the use of the DEM even when four or more satellites are visible. Basically, the DEM serves as a surrogate for one satellite (and is actually more accurate than a satellite would be). If for example four satellites are visible, then without the DEM these satellites would determine one position fix point uniquely, with some significant error. Having the DEM means that there is now effectively one satellite more than is needed for a unique fix, and so the GPS can do a best-fit using all (or as many as are helpful) of the visible satellites. A best-fit using more satellites will in general be more accurate than a unique fix using the minimum number of satellites. Moreover the DEM is oriented in such a direction as to greatly enhance the elevation data accuracy in particular, which is ordinarily the least accurate of the measured coordinates.

Typical GPS receivers have a "2-D" navigation mode in the elevation is treated as fixed, and the satellites are then used to find the X-Y position and velocity under the assumption that the elevation is whatever value at which it is fixed. This mode may give an easy way to implement the DEM-assisted GPS in current receivers, if the local terrain slope is not too extreme. Basically, the trainer 100 would iteratively find the combination of X, Y and Z(X,Y) that is consistent between the GPS and the DEM. The simplest implementation would be to assume that the elevation has not changed significantly since the last fix point. Thus this previous

elevation is input to the GPS as the present elevation; the GPS finds the corresponding X, Y position; then the DEM is used to find the corresponding new elevation (which is presumably not much different from the previous one). This method, though simple to implement, will not be accurate in difficult terrain. It also does not offer any way to calculate the velocity correctly using the vertical component of velocity, dZ/dt. The velocity calculated by a receiver in 2-D mode will be incorrect if the elevation is changing, regardless of whether the receiver is given the correct instantaneous value of the elevation Z.

The more rigorously accurate solution is to incorporate the DEM data directly into the GPS position and velocity equations, essentially imposing additional constraints on the permissible position and velocity solutions. Ideally the solution will use a Kalman filter, a filtering algorithm that integrates all the available data, along with estimates of its potential error (the elevation data will have some error, though less than the GPS measurements), to provide the best possible estimate of the position and velocity at all times. Doing so will more accurately find the location even in highly sloped or variable environments, and it will calculate the velocity correctly.

An additional benefit of the DEM is that the trainer 100, or a user's PC, could generate and display 2-D representations or images of the 3-D terrain, so that the user could examine the terrain visually either before or after traveling in it using the device. Thus a "virtual reality" display showing how the terrain appears would be generated. Desired or completed routes through the terrain could be shown. Moreover, athletes preparing for a race with a particular elevation profile might benefit from software that uses the DEM database to engineer a local training route that has a similar elevation profile to that of the race, and the GPS device could then

guide them along that route. Finally, the DEM might be overlaid with a road map or map of other features of interest to aid in route planning.

The amount of DEM data that a user could ultimately want is very large. The USGS's NED of the entire US would occupy about 20 gigabytes of storage in 16-bit integer format. Therefore at present memory sizes in computers and portable devices, the user is unlikely to wish to carry an entire database of all places where he or she may travel. With its rapidly increasing bandwidth, the Internet provides an ideal solution. An Internet-based server holding the entire country-wide or world-wide database would enable users of the hardware device to download relevant areas of the database to their own PC's and/or GPS devices as needed. Some of the computational functions such as route design or imaging might also beneficially reside on the server rather than in client software.

In some embodiments, the dead reckoning devices 108 includes a barometric-pressure altimeter, which is used instead of a DEM, or in addition to it, to enhance GPS in many of the same ways. The altimeter can have a sensitivity around 10m, thus comparable to that of the DEM. It would have the benefits that it could be used anywhere without requiring the user to pre-load DEM data relating to that area, and that it would work accurately even when the DEM is inappropriate, e.g. when the user is crossing a high bridge, climbing a tower, running up and down stadium stairs, or traveling on terrain that has been altered by land-moving equipment. The altimeter would let the trainer 100 function even if the user was unable to pre-load local DEM data, and it would improve/augment the DEM's accuracy in general, especially in places such as mentioned above where the DEM would be inaccurate or inappropriate. Further, used in conjunction with the DEM, it would provide improved measurement accuracy of barometric pressure for assessment of weather conditions.

In a preferred embodiment, the dead reckoning devices 108 includes an accelerometer or other inertial sensor that is adapted to sense the rhythmic motion associated with a user's athletic performance, e.g. strides, rhythmic arm motion, or slight side-to-side motion of a bicycle in synchronization with the pedaling motion. The purpose of this sensor is further to enhance the performance of the system during periods of partial or complete satellite blockage, as well as to enable smoothing and enhanced accuracy of GPS velocity results. During the periods when the GPS system is generating accurate velocity measurements, these measurements are used to calibrate the inertial sensor, e.g. to establish a relationship between user's speed and the frequency of the rhythmic motion. During these periods, the inertial measurements may also be used to smooth and enhance the GPS results. During periods when the GPS measurements are compromised by satellite blockage, the inertial sensor readings are used in conjunction with the calibration results to extrapolate the user's speed and distance traveled, until contact with GPS is reestablished. It should be noted that the inertial sensor used in this mode does not monitor the user's direction of travel, and that therefore the actual route taken by the user during the satellite blockage may not be accurately recorded. This situation could be remedied by the use of an additional sensor to monitor direction, e.g. a magnetic compass or a gyroscope.

The use of an inertial sensor provides significant additional utility to the user beyond the improved system performance. It enables, for example, a runner's stride length to be monitored and analyzed, and suitable coaching to be offered to optimize performance. Further, in an embodiment in which the trainer also contains a digital-audio player 134 and headphones 136, it enables an audio signal such as music to be

synchronized with the user's stride cadence, providing a substantial motivational enhancement.

In the described embodiment, the GPS enhancement driver 124 provides selected ones of the GPS enhancement factors, including DEM data and inertial sensor data, to the GPS processor 122. In some cases, the selected GPS enhancement factors are determined by the user (based upon manually supplied input by way of the inputs 104) or as directed by a particular training program downloaded by way of the I/O interface 132 to the memory 120 and subsequently executed by the general processor 118. It should be noted that the I/O interface 132 could be any interface suitably arranged to transfer digital data in either a serial or parallel manner. Such interfaces can include an IR type interface, a Universal Serial Bus (USB) port, or any other serial port capable of transferring any particular program.

In the described embodiment, the use of the I/O port allows the trainer 100 to be connected to a computer network, whereby precise satellite location data (ephemeris) can be continually downloaded to the device. If the user commences a training session during the period in which these data remain valid (approximately 3-4 hours following disconnection from the network) then instead of the normal GPS start-up time of 1-3 minutes, the trainer 100 will establish satellite contact in a time of typically several seconds in a procedure known as "hot" starting. This represents a substantial added convenience for the user.

In the described embodiment, the system includes a digital filter such as a Kalman filter, preferentially implemented in software, adapted to provide an optimal estimate of the user's location, speed, and performance by combining all available information from all sensors. This filter may advantageously offer the ability to be tuned for the characteristic movements involved in specific sports; for example, in a

running mode it would be adapted for slower speeds and sharper turns than in a bicycling mode. It may also automatically tune itself for optimum performance with a given user in a given activity, based on prior experience with that user.

In another embodiment, the system may also include a sensor to monitor the user's heart rate. Such a sensor may either be embedded in the device or disposed in a chest-strap type sensor with a wireless connection. Given that chest-strap sensors are in common use today, it may be preferable simply to include a wireless receiver inside the system to receive heart-rate signals from an external chest-strap sensor.

During a typical training session, a user will select whether to use the trainer 100 in a passive mode or in an active mode. In the passive mode, the trainer 100 will use calculate the particular performance parameters (such as instantaneous speed, average speed, distance traveled, elevation gained, etc.). In this way, the user is able to store a particular training session performance parameters in the memory 120 and, if so desired, subsequently download the data by way of the I/O interface 132 to external devices, such as a personal computer, any number of digital appliances (such as a Palm Pilot™), or even directly to a distributed network, such as the Internet where it can be viewed and/or downloaded by any interested party. In this way, a user, as a member of an online group, for example, can post particular training session parameters for others of the group to view and compare.

By allowing the trainer 100 to download software from any appropriate external device, the trainer 100 is capable of being selected to operate in what is referred to as the active mode. In the active mode, selected software, in the form of pre-determined training routines, courses, comparative performance data, and the like, can be downloaded by way of the I/O interface 132 into the memory 120 (if necessary) or, if enough memory is available, directly into the general processor 118

for subsequent execution. By operating in the active mode, the general processor 118 uses real time GPS data provided by the GPS processor 122 to provide real time feedback to the user during any particular training session. One such training mode, referred to as a course mode, is initiated by first downloading particular course parameters (such as location markers and associated speed markers) associated with a desired training course by way of for example, the data interface 118, or by any other appropriate input device, such as a compact disk, flash memory, and the like.

Specifically, a user can select a course on which to train, the parameters are then fed into the trainer 100 either manually during an initialization process, or downloaded from a course database stored in for example a computer that can take any appropriate form such as a desktop, laptop, digital appliance, or one of any number of interconnected computers typical of the Internet. Once the particular course data is available, the trainer 100 provides real time feedback to the user indicating that the user is following the appropriate course and his/her physical performance (such as heart rate based upon input data from a heart rate sensor 138 included in the input devices 104, if the trainer 100 is so equipped) is within an acceptable range.

In another training mode, referred to as a workout mode, the trainer 100 is used to track, in real time, the speed performance of the user based upon a downloaded speed profile. During a training session in the workout mode, the trainer 100 periodically ascertains the instantaneous speed of the user and compares it to the stored speed profile. If the instantaneous speed (or average speed in some cases) falls out of a pre-determined range of speed values based upon the speed profile, a feedback signal is directed at the user. If the user is going too fast, a slow down signal is provided, and conversely, if the user is going too slow then the trainer 100

provides a speed up signal by way of, for example, and headset 140, or other such sound producing device included in the output devices 104. In this way, the trainer 100 provides the user with the capability of accurately following a particular training regimen without the need to have a second party constantly coach or otherwise keep track of the user's performance.

In yet another training mode referred to as a cross-country mode, the trainer 100 provides both spatial and temporal feedback based upon a course profile and an associated speed profile. In the cross-country mode, the trainer 100 provides real time feedback for both location and speed parameters thereby assuring that the user is able to constantly gauge his or her performance against a selected standard. Additionally, by providing real time positional feedback, the possibility of a user becoming lost or otherwise disoriented is greatly reduced.

Fig. 4 illustrates a flowchart describing a process 400 for initializing the trainer 100 in accordance with an embodiment of the invention. At 402, the user turns on the trainer by either connecting it directly to a power source (such as a USB cable, for example) or by simply turning the trainer on. Once power is supplied to the trainer, the GPS processor and the general processor are initialized at 404. In come cases, the initialization of the GPS processor may take some time in order for the GPS processor to locate the position of the various GPS satellites. Once the GPS processor and the general processor have been initialized, external data is pre-loaded into the on-board memory at 406. In some cases, the external data is pre-loaded from a computer coupled to the trainer by way of the I/O interface, and in others, the external data can be data stored in a secondary memory cache included in the trainer 100. Such secondary cache memory can be found in, for example, the general processor or the GPU processor. Once the external data has been loaded, the user selects a

particular operation mode at 408. In the described embodiment, such modes include a passive mode at 410 and an active mode at 412.

Fig. 5 illustrates a flowchart detailing the process 410 whereby the trainer is set to act in the passive mode in accordance with an embodiment of the invention. Once set to operate in the passive mode, the general processor receives instantaneous positional data from the GPS processor at 502. At 504, a determination is made whether or not an enhanced GPS operating mode is desired. If the enhanced GPS mode is desired, then the appropriate GPS enhancements are provided by the GPS enhancement driver to the GPS processor and the general processor at 506. In either case, the general processor calculates various training parameters such as speed, elevation, distance traveled, average speed, and average rate of elevation gain (grade) at 508. At 510, a particular display mode is selected after which the appropriate training results are displayed on the display unit at 512 based upon the selected display mode.

When not selected to operate in the passive mode, the trainer can be selected to operate in the active mode as illustrated by Fig. 6 showing a flowchart detailing the active mode 412 in accordance with an embodiment of the invention. At 601, a user selects a particular training mode after which, at 602, external data based upon the selected training mode is pre-loaded into the on-board memory in the same or similar way in which the external data is downloaded for the passive mode described above. At 604, a determination is made whether or not an enhanced GPS operating mode is desired. If the enhanced GPS mode is desired, then the appropriate GPS enhancements are provided by the GPS enhancement driver to the GPS processor and the general processor at 606. In either case, the general processor calculates various training parameters such as speed, elevation, distance traveled, average speed, and

average rate of elevation gain (grade) at 608 based upon GPS data provided by the GPS processor. At 610, the general processor compares the calculated parameters to those corresponding parameters in the stored data based upon a user selected training mode. At 612, a particular display mode is selected after which the appropriate training results are displayed on the display unit at 614 based upon the selected display mode.

Fig. 7 is a flowchart describing a particular implementation of the mode selection operation 601 as a training mode in accordance with an embodiment of the invention. As shown, in one embodiment, at 702 a user can select a course mode, a workout mode at 704, or a cross-country mode at 706. In the case where the particular selected mode is the course mode, Fig. 8 shows a flowchart detailing one implementation of the course mode 702 in accordance with an embodiment of the invention. At 802, the current position as calculated by the general processor based upon received GPS data is compared to a corresponding position determined by the pre-loaded course. At 804, a determination is made whether or not the current position is consistent with being on course. If the current position in not on course, then a course correction flag is thrown at 806 and control is passed back to 802, otherwise, a determination is made at 808 whether or not the course is complete. If the course is not complete, then control is passed back to 802.

Fig. 9 is a flowchart detailing an implementation of the workout mode 704 in accordance with an embodiment of the invention. At 902, the general processor compares the current elapsed time to a pre-loaded elapsed time marker. A determination is then made at 904 whether or not the user is going too fast, in which case, a slow down flag is thrown at 906 after which control is passed back to 902. If, however, it is determined that the user is not going too fast, then a determination is

made to 908 whether or not the user is going too slow based upon the pre-determined elapsed time marker. If the user is determined to be going too slow, then a speed up flag is thrown at 910 and control is passed back to 902. If, however, it is determined that the user is not going too slow, then a determination is made at 912 if the course is complete in which case control is passed back to 902.

Fig. 10 shows a flowchart detailing an implementation of the cross-country mode 706 in accordance with an embodiment of the invention. At 1001, a comparison is made between the calculated current position and that of an associated pre-loaded course. Based upon the comparison, at 1002, a determination is made whether or not the current position is consistent with being on course. If the current position in not on course, then a course correction flag is thrown at 1004 and control is passed back to 1001, otherwise, the general processor compares the current elapsed time to a pre-loaded elapsed time marker at 1006. A determination is then made at 1008 whether or not the user is going too fast, in which case, a slow down flag is thrown at 1010 after which control is passed back to 1006. If, however, it is determined that the user is not going too fast, then a determination is made at 1012 whether or not the user is going too slow based upon the pre-determined elapsed time marker. If the user is determined to be going too slow, then a speed up flag is thrown at 1014 and control is passed back to 1006. If, however, it is determined that the user is not going too slow, then a determination is made at 1016 if the course is complete in which case control is passed back to 1001.

Fig. 11 illustrates a number of trainers 100 coupled to form a virtual competition 1100 in accordance with an embodiment of the invention. By coupling a number of trainers 100-1 through 100-3 to a server 1102, what is referred to as a virtual competition can be held. By virtual competition it is meant that any number of

competitors 1104, 1106, and 1108, for example, can "virtually" compete with each other without the need for being either spatially and/or temporally juxtaposed. For example, the competitor 1104 is wearing the trainer 100-1 at a location "X_1", whereas the competitor 1106 is wearing the trainer 100-2 at a location "X_2" and the competitor 1108 is wearing the trainer 100-3 at a location "X_3". At a time t_1, the competitor 1102 downloads course data 1112 from the server computer 1102. As described above, the course data 1112 can include maps, elevation gains, training protocols, etc. consistent with the virtual competition. Once the competitor 1102 has completed the prescribed course, results 1114 are sent back to the server computer 1102 and stored in a buffer 1116 (or its equivalent). In a similar manner, at times t_2 and t_3 (each of which can be different from each other as well as time t_1) competitors 1104 and 1106 download their respective course data, upload their respective results which are stored in the data buffer 1116 (or its equivalent) or in any other appropriate memory location or device. Once all the competitor's results have been stored in the data buffer 1116, the server computer 1102 then determines a "winner" taking any number of different approaches. For example, in one scenario, each competitor provides an individual profile that includes such characteristics as age, weight, etc. The server computer 1102 can then process the course data from each competitor and based upon certain weighting factors determine a winner which is then downloaded to each competitor as, for example, a winner's flag 118.

Fig. 12 illustrates a computer system 1200 that can be employed to implement the present invention. The computer system 1200 or, more specifically, CPUs 1202, may be arranged to support a virtual machine, as will be appreciated by those skilled in the art. As is well known in the art, ROM acts to transfer data and instructions uni-directionally to the CPUs 1202, while RAM is used typically to transfer data and

instructions in a bi-directional manner. CPUs 1202 may generally include any number of processors. Both primary storage devices 1204, 1206 may include any suitable computer-readable media. A secondary storage medium 1208, which is typically a mass memory device, is also coupled bi-directionally to CPUs 1202 and provides additional data storage capacity. The mass memory device 1208 is a computer-readable medium that may be used to store programs including computer code, data, and the like. Typically, mass memory device 1208 is a storage medium such as a hard disk or a tape which generally slower than primary storage devices 1204, 1206. Mass memory storage device 1208 may take the form of a magnetic or paper tape reader or some other well-known device. It will be appreciated that the information retained within the mass memory device 1208, may, in appropriate cases, be incorporated in standard fashion as part of RAM 1206 as virtual memory. A specific primary storage device 1204 such as a CD-ROM may also pass data uni-directionally to the CPUs 1202.

CPUs 1202 are also coupled to one or more input/output devices 510 that may include, but are not limited to, devices such as video monitors, track balls, mice, keyboards, microphones, touch-sensitive displays, transducer card readers, magnetic or paper tape readers, tablets, styluses, voice or handwriting recognizers, or other well-known input devices such as, of course, other computers. Finally, CPUs 1202 optionally may be coupled to a computer or telecommunications network, *e.g.*, an Internet network or an intranet network, using a network connection as shown generally at 512. With such a network connection, it is contemplated that the CPUs 1202 might receive information from the network, or might output information to the network in the course of performing the above-described method steps. Such information, which is often represented as a sequence of instructions to be executed

using CPUs 1202, may be received from and outputted to the network, for example, in the form of a computer data signal embodied in a carrier wave. The above-described devices and materials will be familiar to those of skill in the computer hardware and software arts.

Although only a few embodiments of the present invention have been described, it should be understood that the present invention may be embodied in many other specific forms without departing from the spirit or the scope of the present invention.

Although the methods of providing efficient techniques for providing real time athletic performance data in accordance with the present invention are suitable for implementation with personal computers, digital assistants, and the like, the methods may generally be applied in any suitable low bandwidth or high bandwidth distributed data network. In particular, the methods are suitable for use in digital appliances and other low bandwidth networks. Such low bandwidth systems include, but are not limited to: virtual private networks direct serial connections across telephone lines ("BBS systems"), and LANs and WANs regardless of network protocol.

While the present invention has been described as being used with a computer system coupled to the Internet, it should be appreciated that the present invention may generally be implemented on any suitable computer system. Therefore, the present examples are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope of the appended claims along with their full scope of equivalents.

What is claimed is:

In the claims:

1. A portable athletic performance monitoring and training system arranged to provide athletic performance data associated with an athletic performance, comprising:

a GPS receiver having an antenna;

a memory device arranged to store,

a digital elevation model (DEM) database that includes local DEM data used to describe a local elevation profile, and

an athletic performance database that includes velocity data;

a processor coupled to the GPS receiver and the memory device arranged to,

calculate a carrier-wave-Doppler based user velocity using data received from the GPS receiver,

calculate selected athletic performance feedback data using the calculated user velocity and the local elevation profile,

calculate user elevation based upon the DEM database; and

a data I/O port arranged to provide a data interface between the system and an external device; and

a visual display device coupled to the processor arranged to selectively display the performance feedback data

2. A system as recited in claim 1, wherein the system further comprises an inertial sensor adapted to sense rhythmic motion associated with the athletic performance, and wherein the processor includes algorithms selected from the group comprising: the use of inertial-based measurements to provide speed data when GPS data is unavailable, the use of GPS data, when available, to calibrate inertial-based speed measurements, and the use of inertial data to smooth out GPS speed measurements.

3. A system as recited in claim 2, wherein the inertial sensor is selected from a group comprising: an accelerometer and a gyroscope.

4. A system as recited in claim 1, wherein the data transferred through the data I/O port is selected from a group comprising: an athletic training program capable of being executed by the processor, a training route, the local DEM data, digital cartographic data, ephemeris data, a digital-audio file, and user athletic performance data, and wherein the external device is selected from a group comprising: a personal computer (PC), a personal digital assistant (PDA), and a remote server computer and wherein the external device communicates with an Internet server computer via the Internet.

5. A system as recited in claim 4, wherein the Internet server computer provides data selected from the group comprising: DEM data, digital cartographic data, ephemeris data, a database of training routes, a database of athletic training programs, and a selection of digital-audio files chosen to provide motivational enhancement for athletic training.

6. A system as recited in claim 1, wherein the visual display device selectively displays the performance feedback data as a function of the local elevation profile or as a function of the local cartographic profile or as a function of the local cartographic profile and the local elevation profile.

7. A system as recited in claim 1, wherein the visual display device is selected from a group comprising: an LCD, a CRT display, and a plasma discharge display.

8. A system as recited in claim 1, wherein in a workout mode, the processor directs the user through a pre-programmed workout routine based upon a workout mode performance feedback data using a continually updated interface displayed by the visual display device.

9. A system as recited in claim 1, wherein the data received from the GPS receiver is filtered by a sport-specific digital filter in order to maximize accuracy for a particular sport.

10. A system as recited in claim 1 further comprising:
a sensor adapted to monitor the user's heart rate.

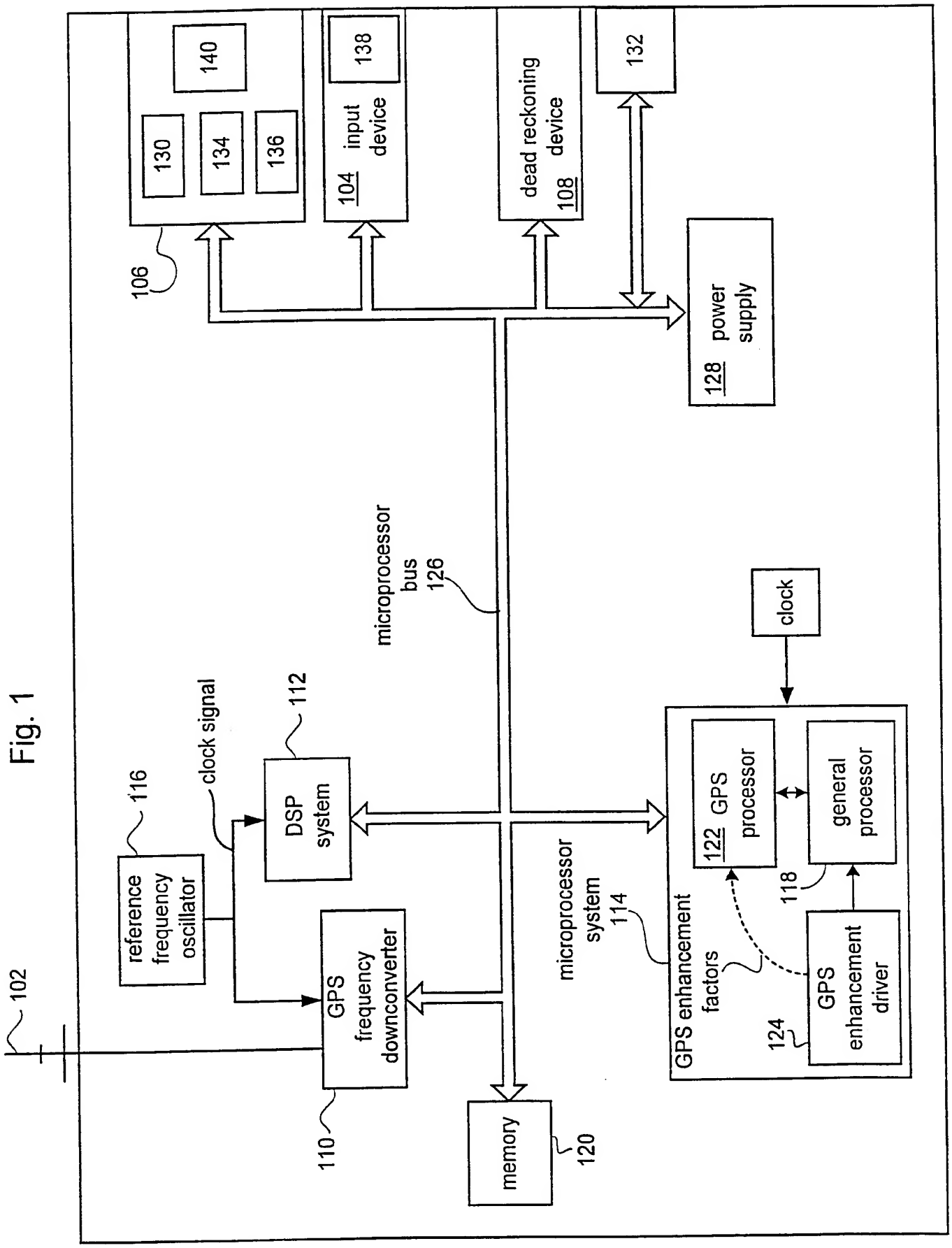
11. A system as recited in claim 1, wherein if local DEM data are not present in the memory device at the time of an athletic performance, the user performance data are post-processed using local DEM data on an external computing device.

12. A system as recited in claim 11, wherein the computing device is selected from a group comprising: a GPS device, a PDA, a personal computer, an Internet server computer.

13. A system as recited in claim 1, wherein the other selected athletic performance feedback data are selected from a group comprising: time elapsed, total distance traveled, elevation, elevation change rate, net elevation change, total elevation gain or loss, calorie expenditure rate, total calories expended, watt expenditure rate, total watts expended, number of strides, stride cadence, stride length, relative performance compared to a previous performance or goals, sport-specific performance scale, and generalized sports overall performance scale.

14. A system as recited in claim 1, wherein the data I/O port is selected from a group comprising: a serial port, a parallel port, a USB port, an IR port, a Bluetooth interface, and a wireless modem.

Fig. 1


102
106
130
134
136
140
104 input device
138
dead reckoning device
108
132
128 power supply
microprocessor bus
126
clock
clock signal
116
reference frequency oscillator
DSP system
112
GPS frequency downconverter
110
memory
120
microprocessor system
114
GPS enhancement factors
122 GPS processor
general processor
118
GPS enhancement driver
124

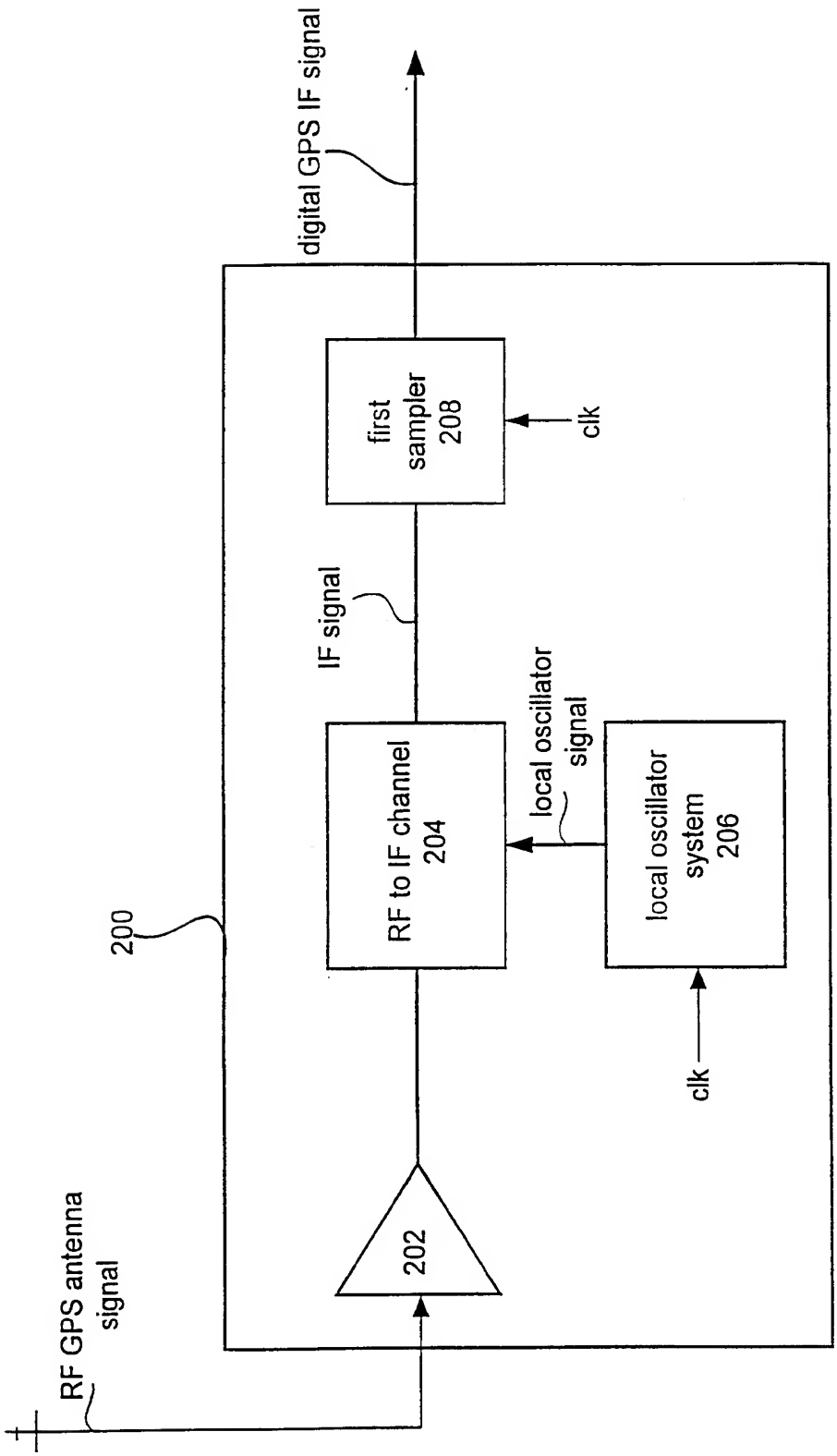

digital GPS IF signal
first sampler 208
clk
IF signal
local oscillator signal
RF to IF channel 204
local oscillator system 206
200
clk
202
RF GPS antenna signal

Fig. 2

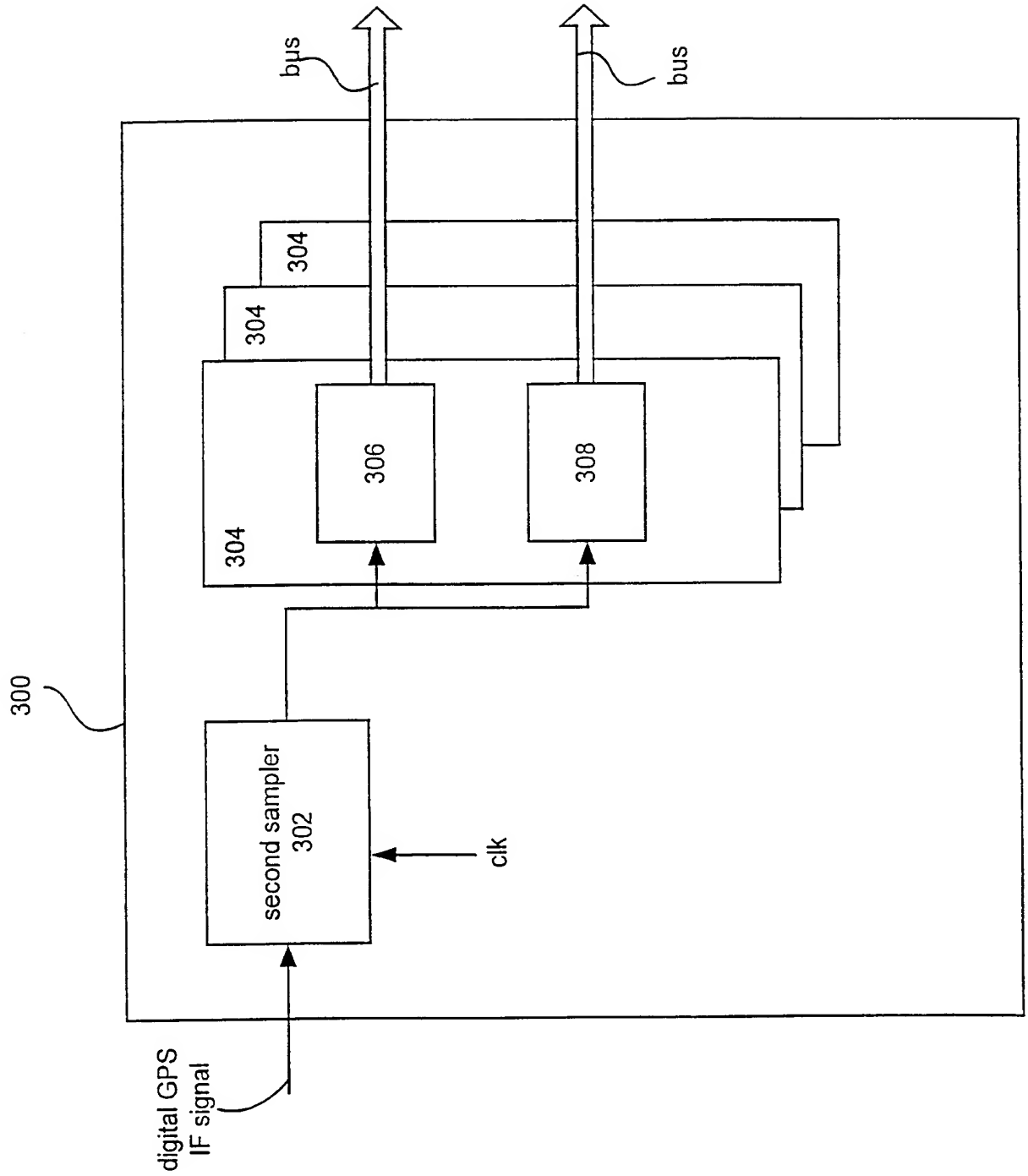
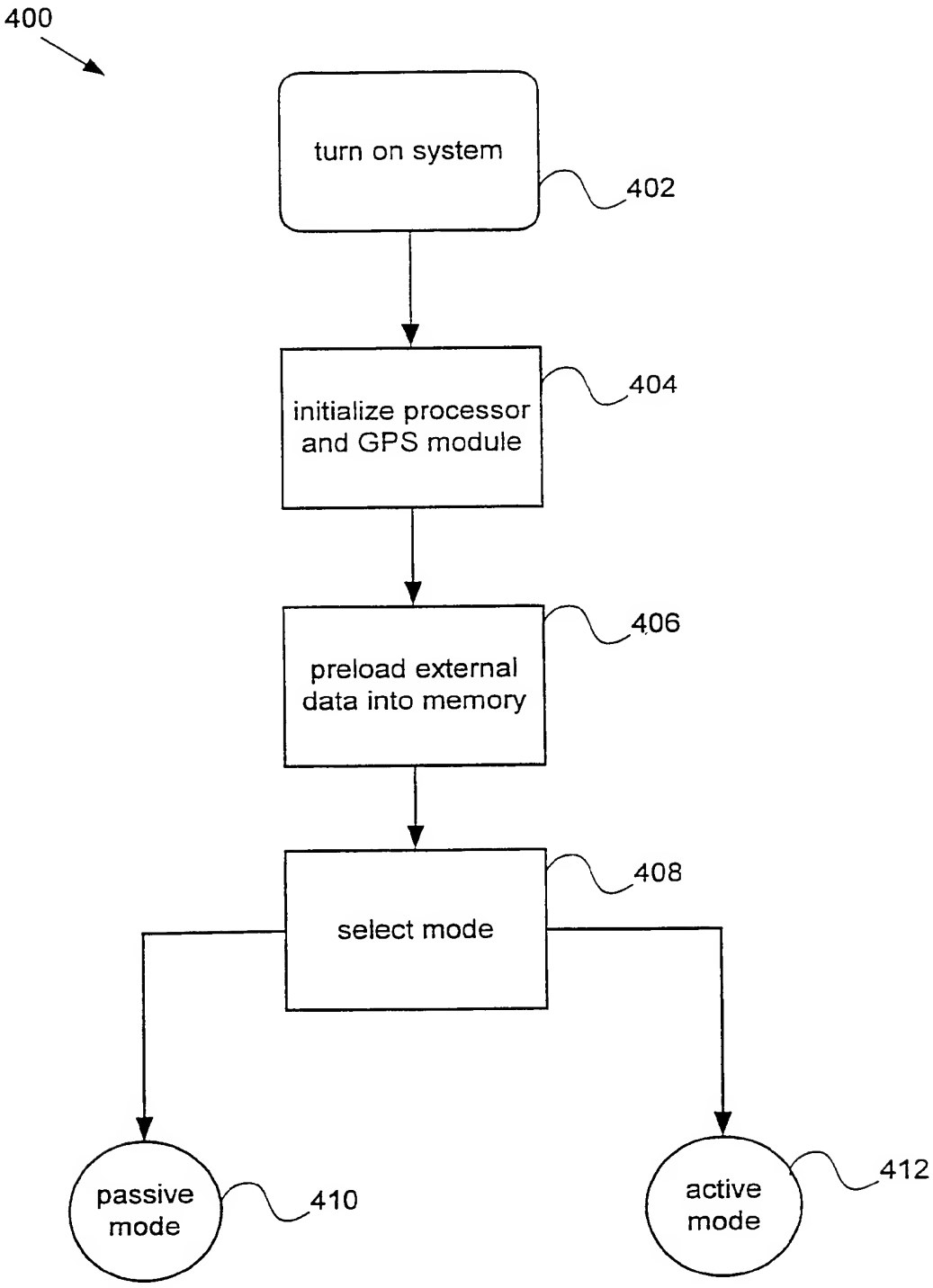

bus
bus
304
304
304
306
308
300
second sampler
302
clk
digital GPS
IF signal

Fig. 3

Fig. 4


400
turn on system
402
initialize processor and GPS module
404
preload external data into memory
406
select mode
408
passive mode
410
active mode
412

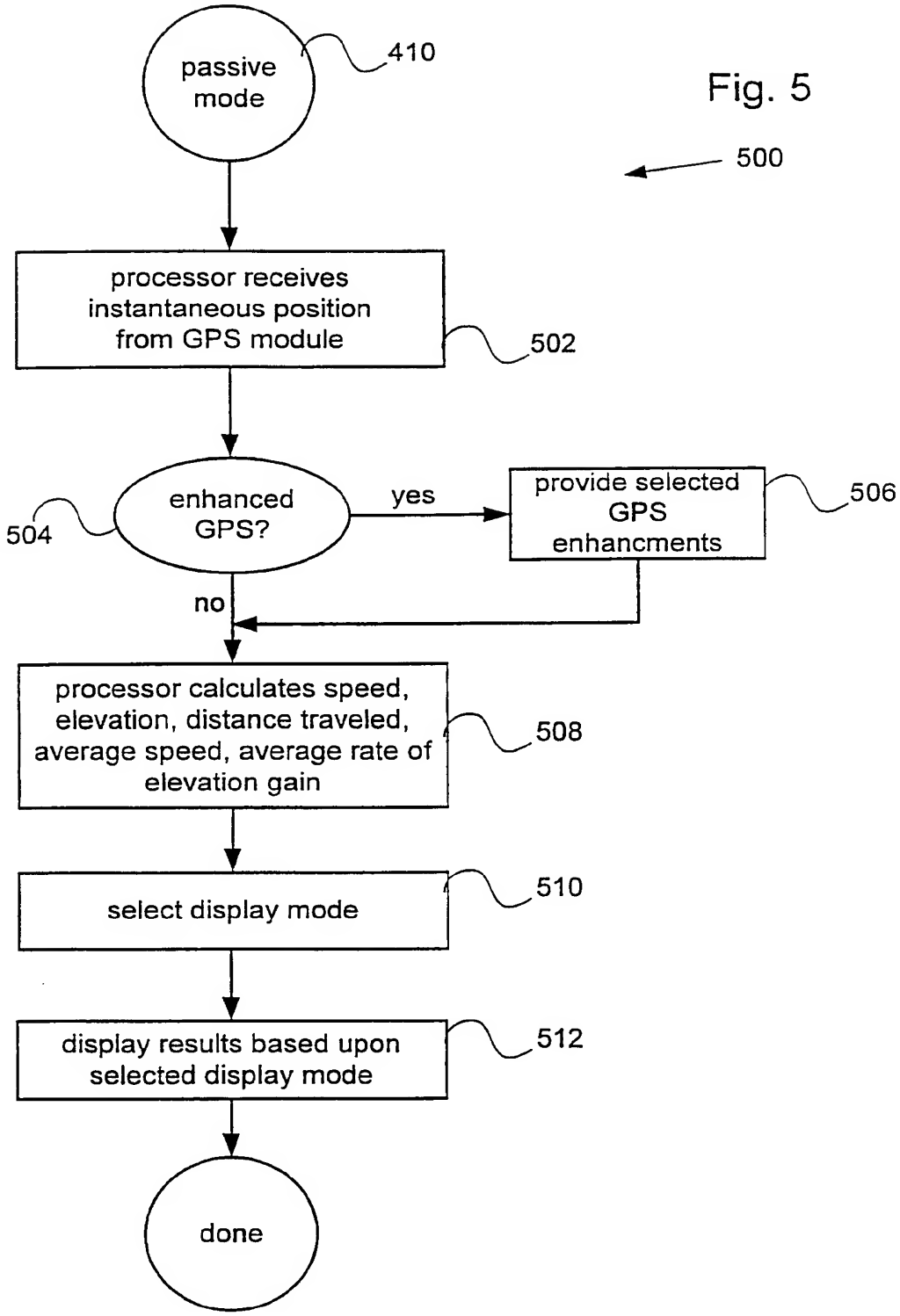
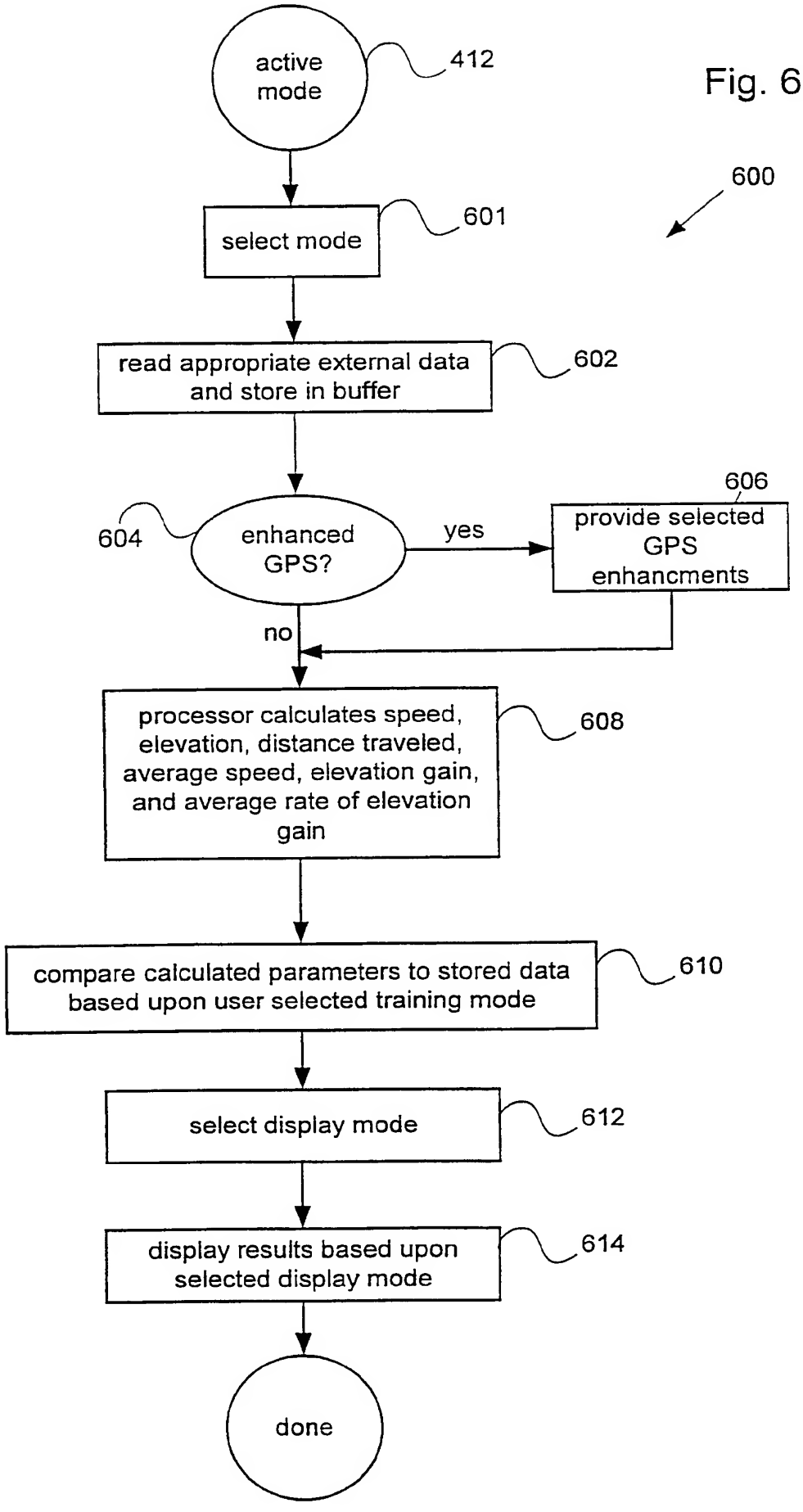

passive mode
410
500
processor receives instantaneous position from GPS module
502
enhanced GPS?
504
yes
provide selected GPS enhancments
506
no
processor calculates speed, elevation, distance traveled, average speed, average rate of elevation gain
508
select display mode
510
display results based upon selected display mode
512
done

Fig. 5

Fig. 6


active mode
412
600
select mode
601
read appropriate external data and store in buffer
602
606
604
enhanced GPS?
yes
provide selected GPS enhancments
no
processor calculates speed, elevation, distance traveled, average speed, elevation gain, and average rate of elevation gain
608
compare calculated parameters to stored data based upon user selected training mode
610
select display mode
612
display results based upon selected display mode
614
done

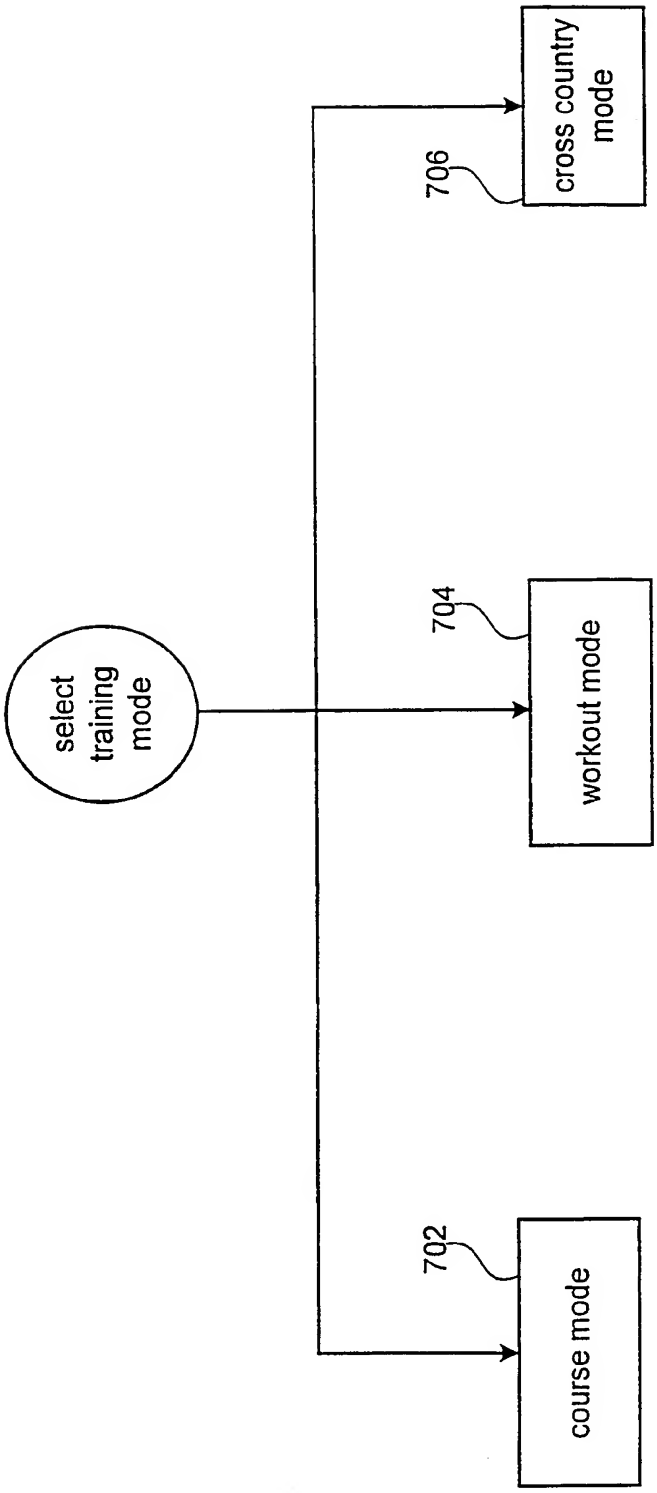
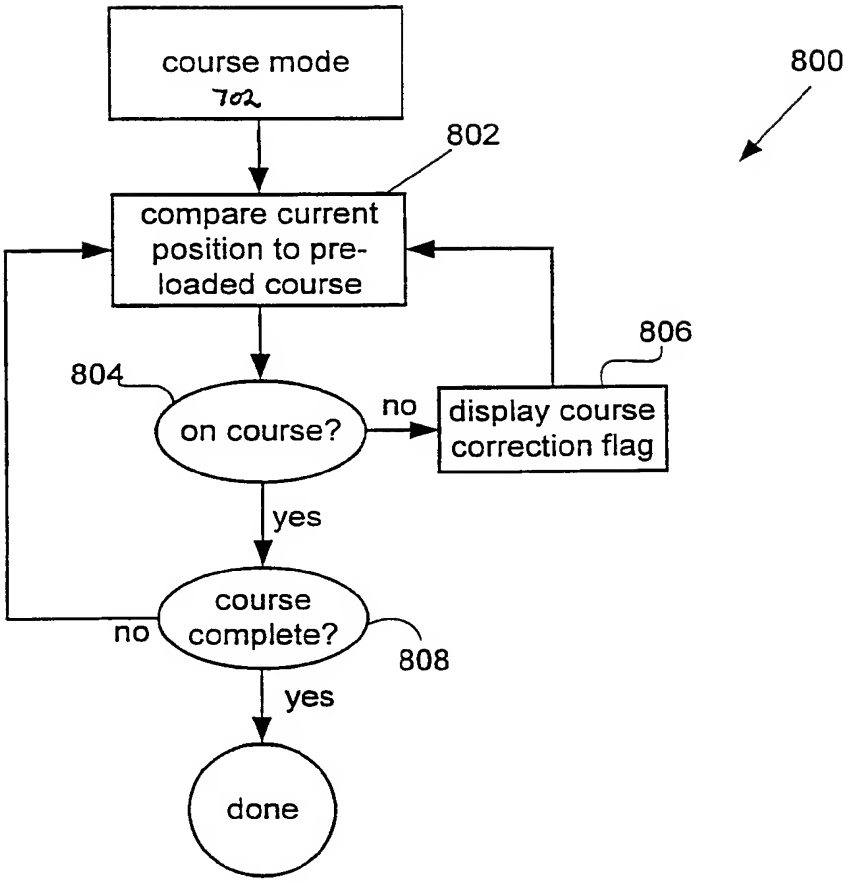

select training mode
workout mode
704
cross country mode
706
course mode
702

Fig. 7

Fig. 8


course mode
702
800
802
compare current position to pre-loaded course
806
804
on course?
no
display course correction flag
yes
course complete?
no
808
yes
done

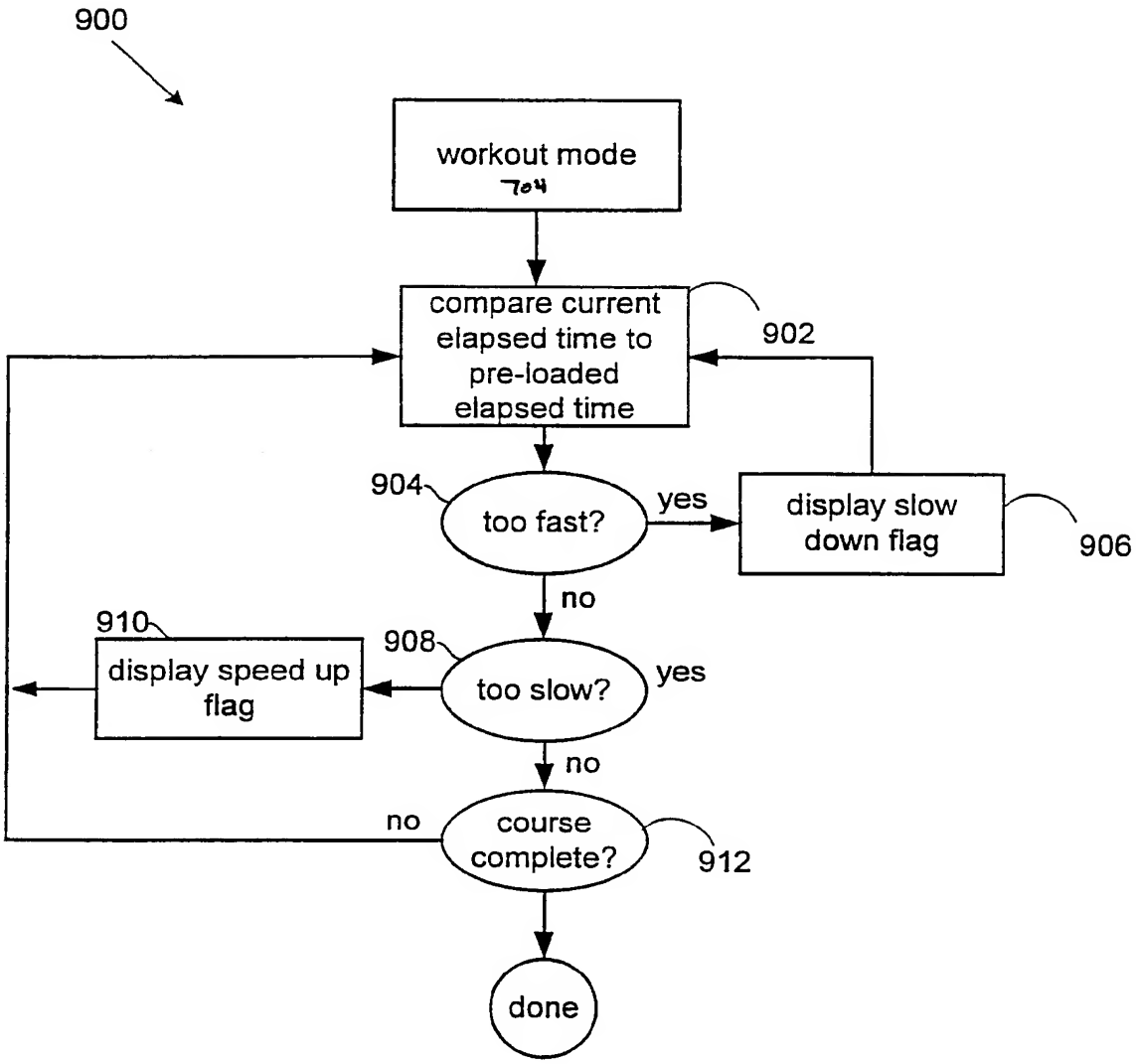

900
workout mode
704
compare current elapsed time to pre-loaded elapsed time
902
904
too fast?
yes
display slow down flag
906
no
910
display speed up flag
908
too slow?
yes
no
no
course complete?
912
done

Fig. 9

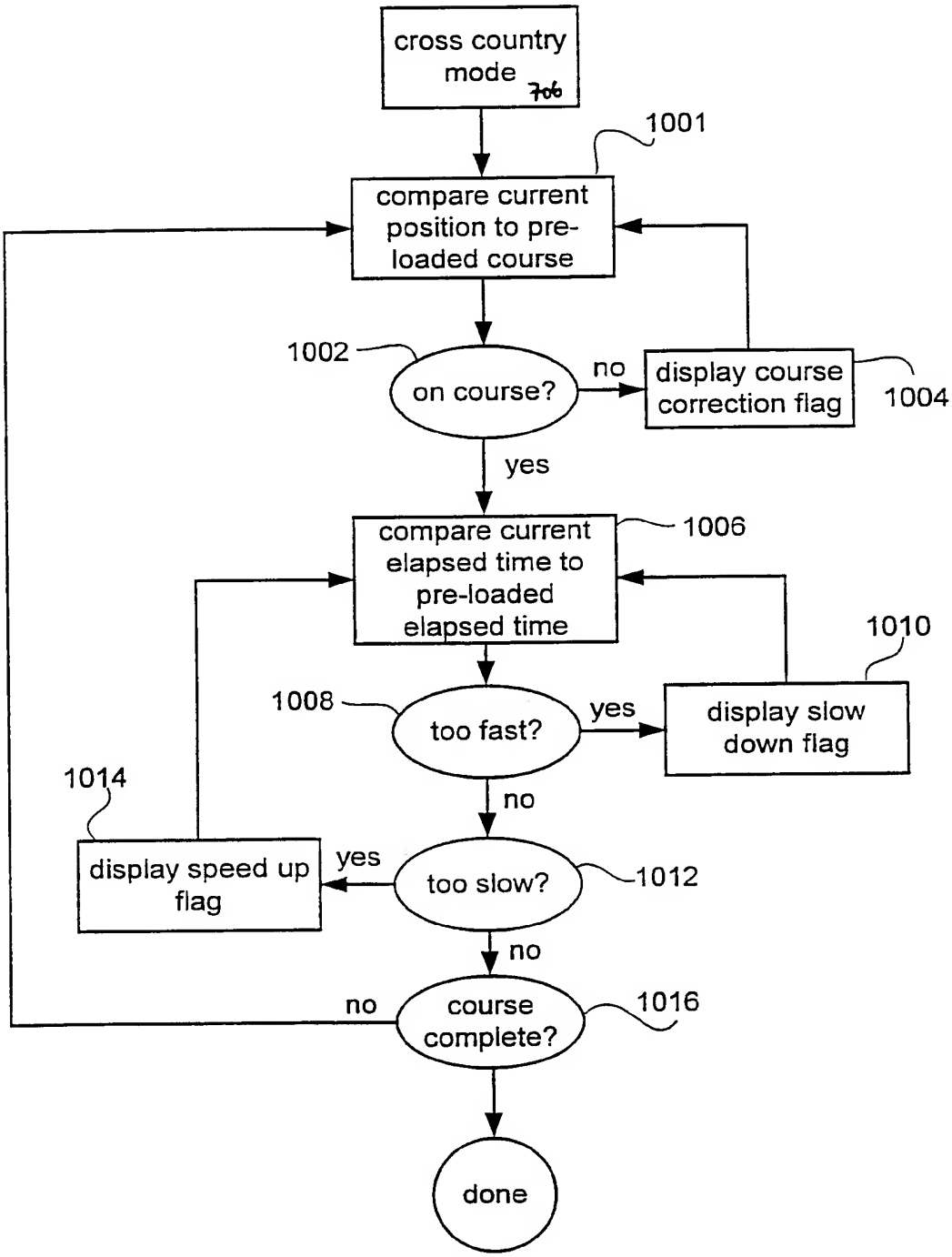

cross country mode 706
1001
compare current position to pre-loaded course
1002
on course?
no
display course correction flag
1004
yes
compare current elapsed time to pre-loaded elapsed time
1006
1010
1008
too fast?
yes
display slow down flag
1014
no
display speed up flag
yes
too slow?
1012
no
no
course complete?
1016
done

Fig. 10

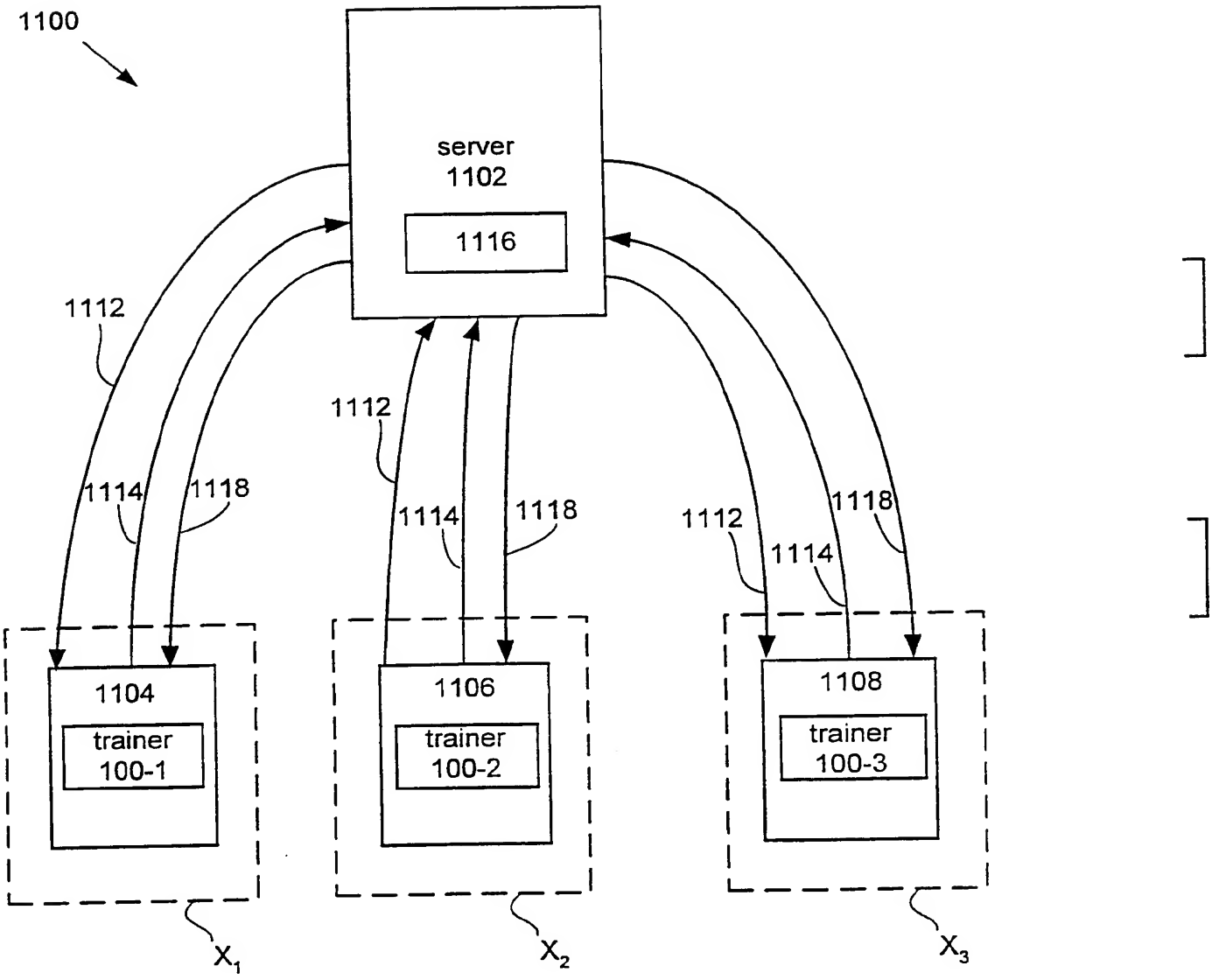

1100
server
1102
1116
1112
1114
1118
1112
1114
1118
1112
1114
1118
1104
trainer
100-1
1106
trainer
100-2
1108
trainer
100-3
X1
X2
X3

Fig. 11

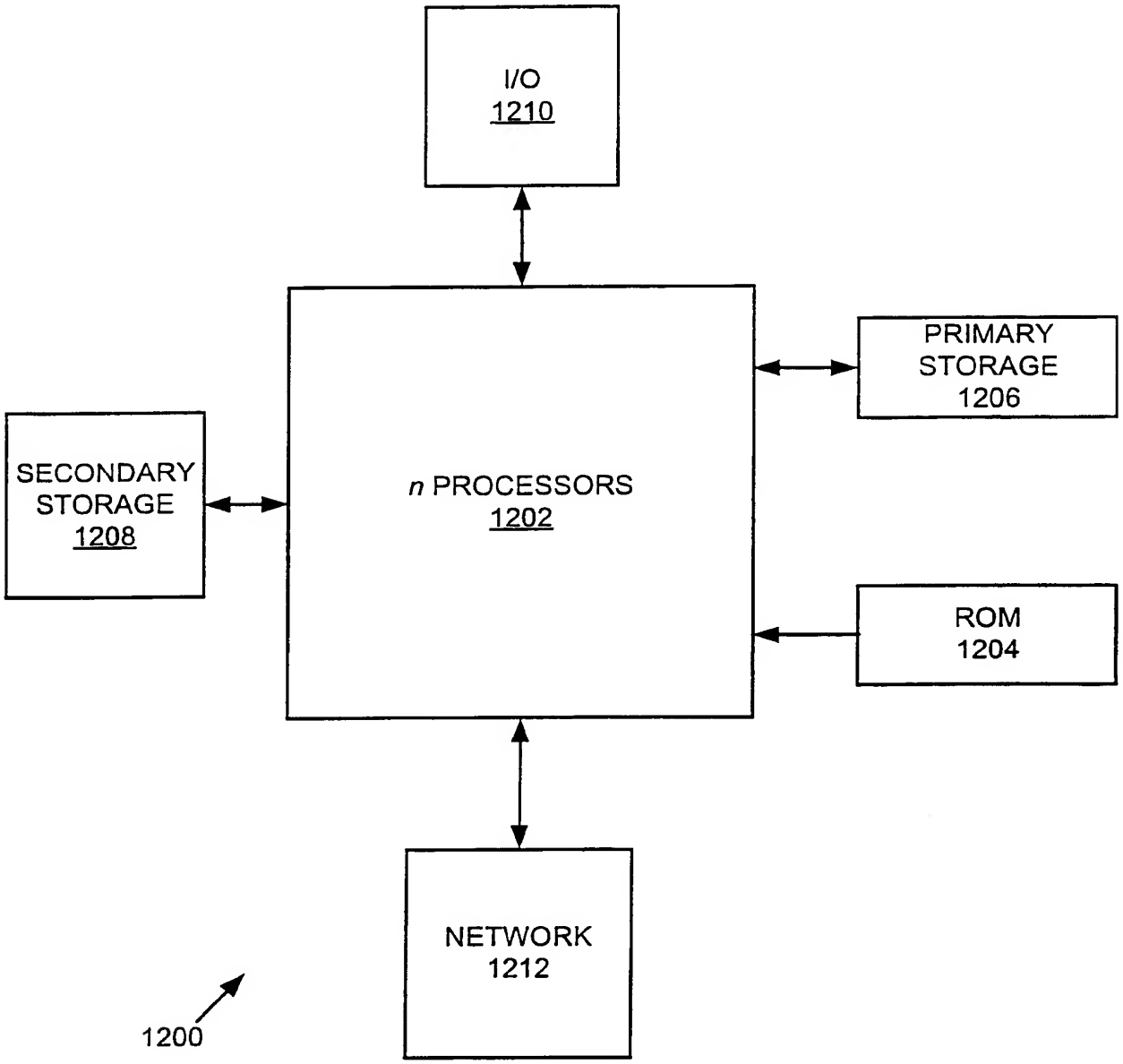

I/O
1210
PRIMARY
STORAGE
1206
SECONDARY
STORAGE
1208
n PROCESSORS
1202
ROM
1204
NETWORK
1212
1200

Fig. 12